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Wisconsin Department of Natural Resources Division of Forestry

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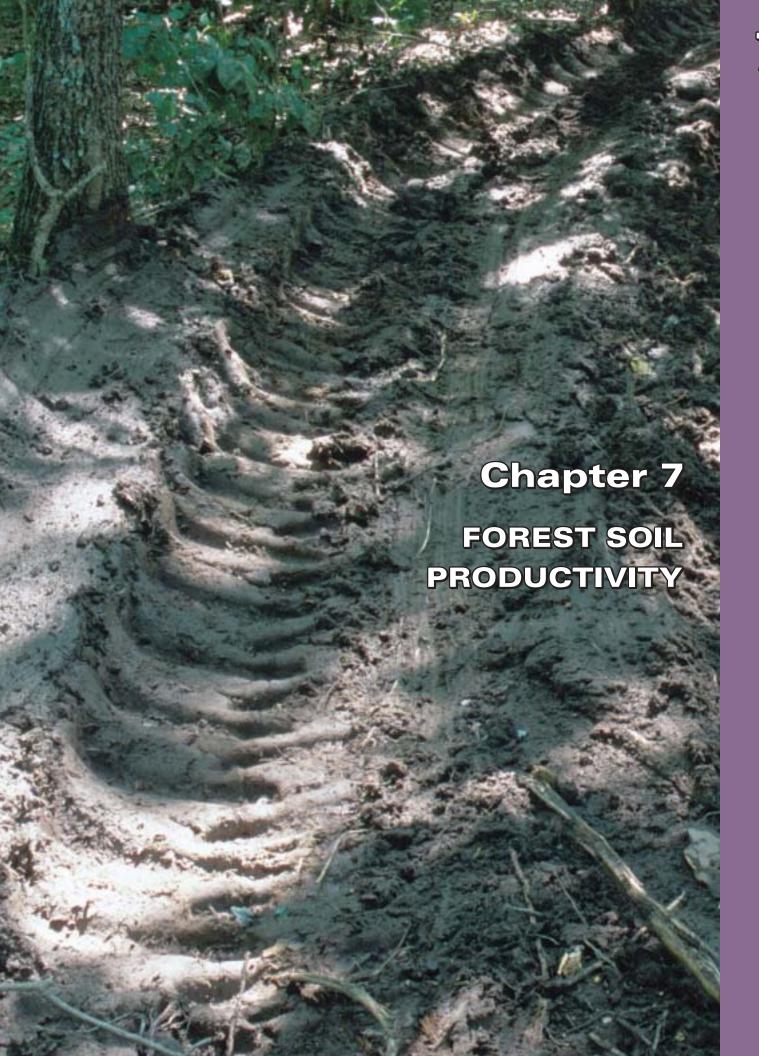
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THE VALUE OF FOREST SOIL PRODUCTIVITY

Figure 7-1: A handful of soil can tell a forester much about the management prospects for a property.

Sustainable Soil Productivity

Soil productivity is defined as the capacity of soil, in its normal environment, to support plant growth. It is reflected in the growth of forest vegetation or the amount of organic material produced by plants and animals. In forest management, soil productivity is often measured in volume of trees produced, but, other methods of determining productivity exist.

Soil is the fundamental resource of the forest. Without it, other resources of the forest would vanish over time. Identifying and reducing impacts to the soil is an essential part of a strategy for sustainable forest management. Primary considerations in maintaining soil productivity include the following:

 Soil productivity is a major factor in determining the amount of timber harvesting that can be sustained over time. It also affects other forest attributes, such as wildlife habitat and biodiversity.

- Soil productivity limits the kinds of tree species that will grow on a site as well as their rate of growth.
- Maintaining soil productivity keeps forest soils in a condition that favors regeneration, survival and long-term growth of desired forest vegetation.
- Maintaining forest soil productivity is less costly than correction or mitigation (after the fact).
- Maintaining the productivity and sustainability of forest soils is key to meeting society's need for forest products and other amenities of the forest.

A certain amount of soil impact is inevitable when conducting some forest management activities. Many of the recommended practices are aimed at keeping this impact to a minimum level.

SOIL CHARACTERISTICS AND POTENTIAL IMPACTS

Three Related Groups of Soil Characteristics

Soils have physical, chemical and biological aspects. All three characteristics are closely interrelated, and impacts on one may influence others.

- The physical properties of soil include such factors as texture, structure, porosity, density, drainage, and hydrology.
- The chemical properties of soil include its nutrient status and rates of cycling, and pH.
- The biological properties of soil include the multitude of organisms that thrive in soil such as mycorrhizae, other fungi, bacteria, and worms.

Because of the nature of forest management activities, the risk or significance of impacts to soil properties appears to be highest for physical properties, followed by chemical properties, and then biological properties. For example, forest sites where nutrient loss has occurred are few, while sites that have suffered due to physical impacts are relatively common. If the physical and chemical properties of the soil are not damaged, then the biological aspects take care of themselves. However, if a soil is severely compacted, plants cannot utilize nutrients because of the poor physical rooting environment, and the soil organisms responsible for nutrient cycling are also limited.

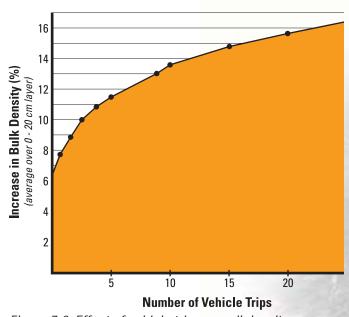


Figure 7-2: Effect of vehicle trips on soil density.

Characteristic 1: Physical Characteristics of Soil and Potential Impacts

Soil physical properties are very important in determining species composition and rate of growth. These properties affect the ease of root penetration and depth of rooting, the availability of water and the ease of water absorption by plants, the amount of oxygen and other gasses in the soil, and the degree to which water moves both laterally and vertically through the soil.

SOIL COMPACTION

Soil compaction is one of several types of closely related physical soil disturbances that can occur during timber harvesting and forest management activities. The other types of physical soil disturbance include puddling, rutting and displacement. These disturbances often occur simultaneously and are almost exclusively caused by movement of heavy equipment during felling, forwarding, skidding, and site preparation operations. Vehicle tires bearing heavy loads compress and pack the soil down, resulting in soil compaction.

Soil compaction is the increase in soil density resulting from loads applied to the soil surface. During the compaction process, soil volume is decreased primarily through the elimination of macropores (pores greater than 0.002 inches in diameter). Pore volume and pore size are key properties that govern air and water movement in the soil. Because of their relatively large diameter, macropores are particularly important in regulating the rates of water and gas movement.

The first few trips with heavy equipment over the soil surface produce the greatest increase in soil density (i.e., the most compaction; see Figure 7-2). Machine vibration may also contribute to compaction.

Recovery of compacted soil is variable depending on the severity of the compaction and local conditions. Compaction is a long-term rather than short-term effect. Severely compacted soils may require up to 40 years or more to recover naturally, according to Hatchell and Ralston, 1971. Froehlich and McNabb, 1984 state that "... the effects of soil compaction should be assumed to persist for several decades on forest sites."

Even in cold climates, where the action of freezing and thawing presumably loosens soils quickly, the density of compacted soils decreases slowly (Voorhees, 1983 and Corns, 1988). In an ongoing study in Minnesota and the Lake States (Stone and Elioff, 1998), no reduction in soil density has been measured after five years of intentional compaction.

Cattle can also cause soil compaction when allowed to trample the soil in forests and woodlots. Damage can be particularly severe when grazing pressure is heavy, soils are wet, and livestock use continues over a long time period. The physical damage to soils begins with the mixing and trampling of the cushioning forest floor layer, which quickly disappears under heavy livestock use. The bare soil is then compacted by repeated trampling – infiltration slows, runoff increases, and soil erosion occurs. Cattle also affect vegetation. In extreme cases, the herbaceous layer may disappear leading to additional loss of infiltration capacity and reductions in soil moisture. Aggressive non-native plants, many of which are spread by cattle, easily invade disturbed areas like these. As forest health declines, litter inputs are reduced and soil organic matter decreases, impacting site fertility. Tree roots may be directly damaged by hoof impacts that create wounds where insects and diseases can enter trees. Seeds, seedlings, and saplings of many tree species are browsed, reducing or eliminating forest regeneration and recruitment. Spiny or thorny plants that cattle do not eat are allowed to grow and may become overabundant, creating an impenetrable bramble. Livestock should be excluded from woodlands that support any quality trees or other desirable vegetation.

Soil compaction can decrease the rate of tree growth by altering the processes involved. Soil aeration is diminished, making oxygen less available for respiration in tree roots. Concentrations of carbon dioxide and other toxic gasses can build up, injuring roots. Soil micro-organisms that play a role in making nutrients available to plants are also negatively affected by the lack of oxygen and high levels of injurious gasses. Compaction further affects root growth by increasing soil resistance to root penetration. It decreases pore space, which reduces soil infiltration capacity (the rate of water movement into the soil), so that less moisture is available for plant growth. Also, when infiltration rates are reduced, more rainfall flows overland, which can increase erosion and sedimentation.

Fine- and medium-textured soils are more easily compacted than coarse, sandy soils. Most compaction occurs when soil moisture conditions are near or at saturation. Dry soils are less susceptible to compaction. Limiting equipment traffic to drier seasons of the year is one way to reduce compaction and other physical damage to the soil. Frozen soils are also relatively resistant to compaction, so winter operations are often an option for wetter sites.

PUDDLING

Puddling is the loss of soil structure that results from squeezing and churning wet soils with the tires or tracks of heavy equipment. Puddling often occurs in ruts with standing water. Soil particles become dispersed in water, and after they have dried and settled, the smaller particles form a crust on the surface. Puddled soils affect forest regeneration and growth in ways similar to compacted soils.



Figure 7-3: Severe soil compaction in this heavily grazed woodlot caused accelerated water runoff, which has eroded a deep gully.

RUTTING

Rutting is the creation of depressions made by the tires of vehicles such as skidders, log trucks and pickup trucks, usually under wet conditions. Rutting occurs when soil strength is not sufficient to support the applied load from vehicle traffic.

- Rutting directly affects the rooting environment. It
 physically severs roots, compacts and displaces soil,
 and reduces aeration and infiltration, therefore,
 degrading the rooting environment.
- Rutting disrupts natural surface water hydrology by damming surfacewater flows, which creates increased soil saturation up-gradient from ruts.
 Alternatively, ruts that run parallel to a slope gradient can divert water flow away from a site, drying or draining it, and sometimes contributing to erosion and sedimentation.
- Soil rutting occurs along with other physical soil impacts, including compaction and puddling.

DISPLACEMENT

The surface layers of most forest soils are very important to site productivity. These layers are rich in organic matter, contain the bulk of the soil's nutrient and moisture-holding capacity, and support the microbial population. Surface horizons cushion soil from traffic and buffer extremes in temperature. Organic matter contributes to soil aeration, and provides sites for seedling germination and rooting. Conserving organic matter is an important factor in maintaining site productivity. Displacement of surface soils, whether moved within a stand or removed from the site, can be detrimental.

Loose, sandy soils are sometimes impacted by heavy equipment that removes or wears away the surface vegetation during skidding and hauling – leaving the soil unprotected. On slopes or roadcuts, these sandy soils can slump downhill due to gravity, or can be eroded by wind and water. The continual displacement of the surface soil prevents revegetation on these areas, and removes them from productivity.

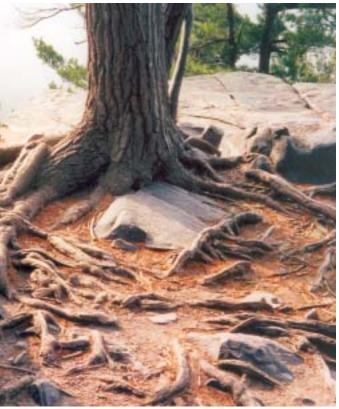


Figure 7-4: In this case, soil compaction and erosion is the result of heavy foot traffic on shallow soil along a popular trail. Injuries to roots and reduced aeration can kill trees. Similar damage can also be caused by livestock grazing, vehicle traffic, and other concentrated land uses.

SOIL EROSION

Soil erosion is a type of physical soil impact that is usually not a factor in forest management in Wisconsin except on roads and skid trails. Erosion seldom occurs on areas with vegetative cover, or on flat areas. Clearcut harvesting that temporarily removes all forest cover on steeper slopes can occasionally result in accelerated erosion. Extra care should be taken on silt, silt loam, loam, very fine sandy loam, sandy clay loam, silty clay loam and clay loam soils, as these soils tend to erode more easily when disturbed or exposed, especially on long slopes or slopes greater than 10 percent.

PROTECTING SOIL PHYSICAL PROPERTIES

 Compaction and Rutting: Soils most susceptible to compaction and rutting include fine-textured soils (silty clay, sandy clay and clay) and medium-textured soils (fine sandy loam, very fine sandy loam, loam, silt loam, silt, silty clay loam, clay loam, and sandy clay loam).
 Poorly and very poorly drained soils of any texture are susceptible to compaction and rutting during most years when not adequately frozen.

The susceptibility of soil to compaction and rutting is primarily dependent on soil texture and moisture content. Soils are most susceptible to compaction, puddling and rutting when they are saturated. Such conditions occur during spring and early summer months, immediately following heavy rains, and in the fall after transpiration has ceased but before freeze-up.

Timing of forest management activities, development of infrastructure, and selection of equipment and operating techniques are all critical factors that affect the soil resource. It is important to avoid operating heavy equipment on a site when adverse soil impacts are likely, and to limit direct trafficking of a site to the smallest area possible.

The preferred operating season for any one site may vary depending on local climatic conditions, equipment being used, and operating techniques. The use of low ground pressure (LGP) equipment and operating techniques such as the use of slash mats can extend operating seasons on low-strength soils. Infrastructure development, including roads, landings and skid trails, almost always results in direct soil compaction and reductions in forest growth. It is critical to minimize the area occupied by infrastructure to reduce the impact to soil productivity. For more information on how to obtain soil interpretations for equipment operation, see the Resource Directory.

 Soil Displacement: Mechanical site preparation techniques often involve soil displacement. Severe treatments that remove or displace the surface organic and mineral soil layer may result in nutrient removal and other site degradation (i.e., soil erosion or compaction).

Site preparation techniques that move surface soil away from seedlings (e.g., dozing soil into windrows) should be avoided, as these practices remove much of the nutrient and moisture supply that a seedling needs.

The loss of surface soil is exaggerated with extremes of soil types. Coarse, dry soils and wet, fine soils, or soils shallow to bedrock, are most likely to be severely impacted (see Chapter 13: Mechanical Site Preparation, for more discussion on selecting methods).

Retaining slash on site provides shelter and organic matter for seedlings. Although it may be difficult to plant a site with slash present, windrowing or piling of slash should be avoided, and scattering of slash should be encouraged.

Prescribed fire is sometimes used to reduce slash before planting, control competing vegetation, or expose mineral soil for seeding. Fire "mineralizes" soil nutrients, making them readily available to plants, but leaching can also occur. Fire-adapted ecosystems in Wisconsin are generally restricted to sandy outwash plains, where vegetation is adapted to fire and can take up the nutrients quickly. However, sites without native ground vegetation may be subject to leaching losses. Extremely hot fires may volatilize some nitrogen, but most is retained under conditions prevalent in most prescribed burns.

Erosion can be a severe problem on roads and skid trails that lack vegetative cover, resulting in downcutting of the roadbed and sediment delivery to streams. Techniques for limiting soil erosion and sedimentation from roads are discussed in Chapter 11: Forest Roads.



Figure 7-5: Excessive ruts caused by logging equipment should be dealt with promptly – before rain or melt water turns them into major gullies.



Figure 7-6: Soil compaction and rutting can create areas where water infiltration is slowed and ponding occurs. These ponds may benefit amphibians, but reduce forest productivity, and limit equipment travel. On slopes, such sites can result in erosion and sedimentation.

Characteristic 2: Chemical Characteristics of Soil and Potential Impacts

Soil chemical properties include nutrient status of a soil and soil pH. Soil chemical characteristics are influenced by many factors, including soil origin, soil texture and drainage, degree of soil weathering and development, and organic matter content. Forest management affects the nutrient status of a soil/site through 1) removal of nutrients in forest products, and 2) disturbance of surface soils through harvesting and site preparation activities.

NUTRIENT CYCLING

Nutrient cycling is the process by which nutrient elements move into, out of and within an ecosystem. Forested ecosystems receive natural inputs of nutrients through atmospheric deposition and mineral weathering (see Figure 7-7).

Throughout the life of a stand, these inputs can be very significant. Outputs of nutrients occur through timber harvesting or other practices that remove soil or organic material from a site, and through leaching and surface runoff.

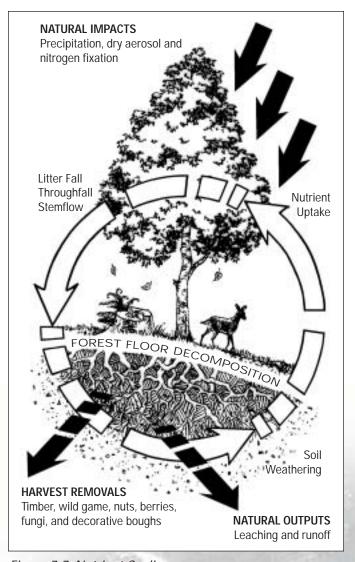


Figure 7-7: Nutrient Cycling

In contrast to the annual harvests associated with agriculture, a forest harvest typically occurs only once per rotation, or every 40 to 120 years. This reduces the rate of nutrient removal as compared with agriculture, and allows sufficient time for replacement by atmospheric deposition and weathering of soil minerals.

In forest ecosystems, timber harvesting and some site preparation practices can remove nutrients and have the potential to create deficiencies. Nutrient depletion could occur if removal is greater than replenishment that occurs between harvests. The likelihood of nutrient depletion is greater with shorter rotations, nutrient-demanding species, whole tree harvesting, and on sites with low inherent nutrient reserves.



Figure 7-8: Retaining slash on skid trails is an effective way of reducing soil compaction and rutting from use of heavy logging machines.

NUTRIENT STATUS AND REMOVALS

The initial nutrient capital of a site varies widely by soil type. For example, a loamy soil formed in loess over glacial till may contain several times the amount of calcium in the rooting zone, than a sandy soil formed in outwash deposits.

Different nutrients are stored in different parts of a tree, and different tree species store the nutrients in different relative abundance. In general, the greatest portion of mineral nutrients is stored in the leaves, followed by small branches, large branches, and boles (Kramer and Koslowski, 1979). Some species, however, store more calcium and magnesium in the bark than in the leaves. For example, aspen utilizes a relatively high amount of calcium, and stores roughly 50 percent of the calcium in the bole-wood and bark. Harvesting species that store relatively high levels of nutrients in the bole-wood and bark will potentially remove greater amounts of nutrients from a site.

Nutrient removal associated with timber harvest is dependent on 1) the species and portions being harvested, and 2) the season. For example, a whole-tree harvest during the growing season will remove virtually all nutrients stored in the above-ground part of the trees. In the case of bole harvest, with limbing at the stump, nutrients in the crown and other non-merchantable portions are retained on site. If trees are skidded to a

landing before limbing, the nutrients in the crown are removed from the immediate vicinity, but could be moved back into the stand.

There is no evidence that nutrient depletion has occurred in Wisconsin due to forest management. Studies in Michigan on sandy outwash soils found nutrient depletion in conjunction with whole-tree aspen harvest (Stone, 2001). This could become a concern for sites with similar characteristics.

NUTRIENT-RETENTION STRATEGIES

- · Retain or redistribute slash on the site
- Avoid whole-tree harvesting
- · Addition of nutrients to the site
- · Avoid shortened rotations

Many modern harvesting systems require full-tree skidding for efficiency of the operation. In these situations, slash can be redistributed out to the site from the landing. Caution should be exercised during non-frozen seasons to avoid trafficking additional areas while redistributing slash. The negative effects of soil compaction due to increased trafficking could outweigh the positive benefits of redistributing slash. It may be advantageous to leave clumps of slash (drags left along skid trails) or leave slash in the skid trails.

Characteristic 3: Biological Characteristics of Soil and Potential Impacts

 Biological characteristics of soil include the populations of plants and animals, including microflora (fungi, bacteria, algae) and microfauna (worms, arthropods, protozoa). Forest soils contain a multitude of microorganisms that perform many complex tasks relating to soil formation, slash and litter decomposition, nutrient availability and recycling, and tree metabolism and growth. Generally, the number of organisms are greatest in the forest floor and the area directly associated with plant roots (Pritchett, 1979).

The population of soil organisms (both density and composition) and how well that population thrives is dependent on many soil factors including moisture, aeration, temperature, organic matter, acidity, and nutrient supply (Pritchett, 1979).

- Mycorrhizae are soil fungi that grow into tree root hairs, forming a symbiotic relationship that is very important in nutrient uptake for most tree species, particularly on nutrient-poor sites. Mycorrhizal tree species include pines, spruces, firs, maples, ashes, birches, beeches, oaks, basswoods, black walnut, black cherry, and willows. Afforestation has proven difficult in areas where mycorrhizae are not present in the soil, and trees planted in such sites are sometimes inoculated with a mycorrhizal fungus to improve establishment. Loss of the forest floor layer, or deforestation that dries and warms a site, can negatively impact populations of mycorrhizal fungi.
- Infiltration of moisture into the soil is aided by dense ground vegetation and thick forest floor, or duff layers, that act to intercept and hold rainfall. Activities that remove or thin the herbaceous plant cover and duff layer will contribute to greater runoff and potential erosion. The use of vehicles in forested sites can damage ground vegetation and remove or displace the forest floor layer. Trampling and grazing by cattle can also have these effects, particularly when combined with soil compaction that also reduces infiltration capacity. Some non-native invasive shrubs contribute to reduced infiltration, by capturing virtually all available sunlight so that no herbaceous plants grow beneath them, leaving the soil bare and unprotected.

- "Pit and mound topography" is a term that refers to the soil surface in a forest where occasional large trees have fallen or been blown down. The tree's root system pulls up a mound of soil, leaving a pit where the tree formerly stood. These pits are important sites for water infiltration into soils, especially on slopes, and also create puddles and ephemeral pools that benefit amphibians and invertebrate organisms. Harvesting reduces the likelihood of treefalls that create pits and mounds, and equipment travel tends to smooth the surface of forested sites. Maintaining a component of reserve trees that are allowed to fall down can help retain pit and mound topography.
- Physical and chemical soil characteristics can be influenced by forest management as previously discussed. Impacts to these soil properties may directly impact soil biology, thereby impacting the functions of the organisms – many of which are beneficial to plant growth. Implementation of practices that protect the physical and chemical properties of the soil also protects the habitat of the soil organisms and sustains their populations.

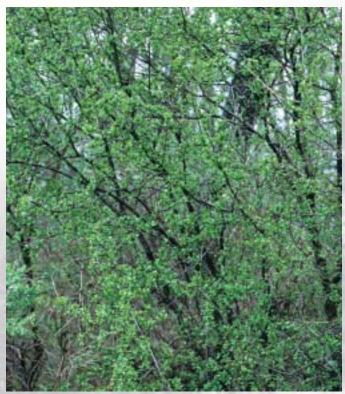


Figure 7-9: Buckthorn, a non-native invasive species, has invaded this woodland in southern Wisconsin, depleting vital nutrients needed by more desirable species.

APPLYING GUIDELINES TO VARYING SITE CONDITIONS

Forests in Wisconsin grow on a variety of soils and site conditions. Some of these include 1) loamy and clayey soils formed in rolling glacial till, often overlain with a silt loam "loess cap" deposited by wind after glaciers melted, 2) silty or loamy soils formed in alluvial plains along rivers, 3) droughty sands formed in outwash plains or sandy lake sediments, and 4) organic soils formed in wetlands.

Topography also varies greatly throughout Wisconsin. Much of the state displays glacial features like steep, hilly end moraines, gently rolling ground moraines, and nearly level outwash and lake plains. The "Driftless Area," which was not glaciated during the Wisconsin Ice Age, has steep eroded hillsides and level valley bottoms. The Lake Superior clay plain has fine-textured clay soils that are highly-erodible, and if not managed properly can contribute a significant amount of sediment to streams.

Because site conditions vary, it is important for individuals making forest management decisions to evaluate the soil and topography of each site. Site-specific information helps the manager develop individualized prescriptions to ensure productive capacity is not reduced as a result of forest management activities.



Figure 7-10: Skidder traffic, and hence soil compaction, can be reduced when the operator pulls cable to the logs instead of driving the machine to each one.



Figure 7-11: Retaining slash may be a bit unsightly, but it provides some shelter for new seedlings and adds organic matter and nutrients to the soil. When crushed by heavy equipment, it decomposes rapidly.